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**UTILIZING HEARING ASSISTIVE TECHNOLOGY (HAT) TO ASSESS  
SPEECH RECOGNITION: COMPARISON OF WORD RECOGNITION  
SCORES OBTAINED BY HEARING INSTRUMENT USERS**

**by**

**Stephanie Schutzenhofer**

**A Capstone Project  
Submitted in partial fulfillment of the  
requirements for the degree of:**

**Doctor of Audiology**

**Washington University School of Medicine  
Program in Audiology and Communication Sciences**

**May 21, 2010**

**Approved By:  
A.U. Bankaitis, Ph.D., Capstone Project Advisor  
Michael Valente, Ph.D., Secondary Reader**

***Abstract: The ability for individuals with hearing loss to accurately recognize correct versus incorrect verbal responses during traditional word recognition testing across four different listening conditions was assessed.***

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Stephanie Schutzenhofer  
May 2010

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## **CHAPTER I**

### **Introduction & Literature**

It is projected that by 2010, slightly over 33 million people in the United States will have a hearing loss (BellaOnline, 2009). As such, a large percentage of the population could certainly benefit from habilitative or rehabilitative services from audiologists. Given the demographic trends of hearing loss in the general population, it is anticipated that a percentage of individuals with varying degrees of hearing loss will pursue Audiology as a primary profession. Since one of the roles of an audiologist is to diagnose hearing loss, the hearing status of the audiologist becomes a critical issue, particularly during testing procedures that place increased demand on auditory acuity on the part of the tester, such as speech audiometry, hearing instrument listening checks, and speech-language screening. While audiologists with hearing loss may be in a better position to empathize with patients who are diagnosed with hearing loss, the ability to hear patient responses accurately during various testing procedures is paramount.

It remains unclear as to the number of audiologists currently in practice who have been diagnosed with hearing loss. A survey conducted by the American Speech-Language Hearing Association (ASHA, 2002) revealed that of 1,417 audiologists that responded, 3.9% had an “auditory” disabling condition. More recently, Schutzenhofer (2008) informally surveyed 67 AuD programs, inquiring as to the number of students identified with hearing loss who were actively enrolled in doctoral level audiology programs. Based on responses from 37 of the 67 programs (55% response rate), approximately 5% of audiology students currently enrolled in



AuD programs have some degree of hearing loss. In terms of difficulty in assessing patients, Yoder and Pratt (2005) surveyed “hard-of-hearing” audiologists, specifically asking audiologists questions pertaining to their perceived challenges in testing patients as a direct result of their own hearing loss. Of the 41 audiologists and audiology students responding to the survey, an overwhelming majority (78%) expressed difficulty in performing audiometric test procedures due to their hearing loss.

### **Need for Supplemental Hearing Technology Beyond Hearing Instruments**

The ability for audiologists with hearing loss to accurately score speech audiometry represents an area of concern for employers and supervisors since this task requires the audiologist to accurately hear the verbal responses presented by the patient. Depending on the degree, configuration, and specific site-of-lesion, sensorineural hearing loss is associated not only with attenuation of sound, but with varying degrees of signal distortion. This distortion will interfere with word recognition performance. However, the expectation is for audiologists with hearing loss to score patients’ performance on word recognition tests as accurately as audiologists with normal hearing.

Hearing instruments do provide significant benefit to those with hearing loss; however, hearing assistive technology (HAT) in conjunction to hearing instruments may provide the necessary advantage to ensure that word recognition tasks are scored as accurately as normal hearing audiologists. According to Yoder and Pratt (2005), most of the compensatory strategies employed by audiologists with hearing loss as it pertains to speech audiometry involves strategic positioning of patients in the audiometric testing booth such that the clinician can see the patient which would thereby facilitate lip reading (Yoder and Pratt, 2005). While this compensatory

strategy may make it less difficult for audiologists with hearing loss to accurately perform word recognition testing, there is no evidence to suggest that this application assists in achieving accurate word recognition scores.

### **Hearing Assistance Technology**

Hearing assistance technology (HAT) refers to a broad range of devices beyond traditional hearing instruments designed to facilitate the reception of auditory information (Thibodeau, 2004). Examples of HAT devices include both corded and cordless amplified telephones, telephone amplifiers, telephone ringer amplifiers, infrared devices, FM systems, and various alerting devices. Regardless of the specific type of device, the intent of HAT is to optimize communication for individuals with hearing loss (Keller, 2006). This is primarily achieved by bridging the distance between the speaker and the listener. This improves signal-to-noise ratios (SNR) for purposes of creating the most conducive environment for speech recognition. SNR refers to the relationship between the sound level of a signal and of the noise at the listener's ear (Mendel, Danhauer and Singh, 1999). It is generally reported as the difference in decibels (dB) between the intensity of the desired signal and the intensity of the undesired noise (Agnew, 2002). The SNR may be reported either as a positive or negative number. For example, a SNR of +5 dB indicates that the desired signal is 5 dB *louder* than the undesired noise. Conversely, a SNR of -10 dB specifies that the signal is 10 dB *softer* than the background noise. Considering these two examples, a SNR of +5 dB is a more favorable listening situation than an SNR of -10 dB. For those with sensorineural hearing loss, the more favorable the SNR, the easier it will be for individuals to hear, thereby optimizing communication.

With regard to audiologists with hearing loss who are wearers of hearing instrumentation, the most applicable types of HAT for use in the clinical setting include coupling the hearing instrument with some type of induction device or to some type of FM system. In terms of an induction device, hearing instruments must be equipped with a telecoil (t-coil). The t-coil is also referred to as an induction coil. A t-coil is a magnetic transducer consisting of a coil of wire that is encased in a hearing instrument. It acts like a magnetic field sensor (Thompson, 2002). When placed in an electromagnetic field, an alternating electrical current is induced in the t-coil, causing it to change the electromagnetic energy into electrical energy (Ross, 2005). The electrical signal is then amplified by the hearing instrument, and eventually re-converted to an acoustic signal. Depending on the FM system, the hearing instrument may not necessarily require a t-coil. For those FM systems designed to interface with hearing instrument via an induction device, such as a neckloop, a t-coil is required. In other cases, FM systems may interface with hearing instruments via direct audio input (DAI). This refers to a feature of a behind-the-ear (BTE) hearing instrument that enables an external source to be connected to a BTE directly, bypassing the instrument's microphone. In this particular case, connecting the FM system via DAI will require an audio "shoe" or "boot". This device resembles a small sleeve that fits over the end of a BTE, allowing the introduction of different input signals directly to the hearing instrument than to the hearing instrument's microphone. To further illustrate this type of HAT, the following sections will provide an overview of specific products.

### *NoiZfree Induction Earhook*

The NoiZfree induction earhook ([www.noizfree.com](http://www.noizfree.com)) shown in Figure 1, is an example of an induction device specifically designed for use with non-bluetooth enabled cell phones and other audio sources. This induction earhook will work with t-coil equipped hearing instruments only. It is comprised of a 30” cord that contains a lightweight induction earhook on one end and a 2.5 mm jack on the other end. The earhook resides behind the ear and the 2.5 mm jack plugs directly into the cell phone via the headset port. In order to use this particular device with a cell phone, the hearing instrument must be switched to the t-coil mode. Conversations from the cell phone are routed via the wire extending from the cell phone to the induction earhook. The induction earhook sends cell phone conversations electromagnetically to the hearing instrument’s t-coil, enabling the user to hear cell phone conversations directly via their hearing instruments. The earhook is available in monaural and bilateral configurations.

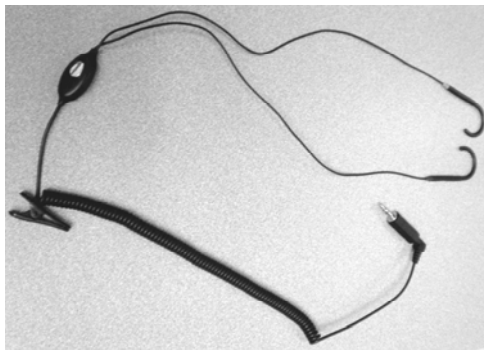


Figure 1: Bilateral NoiZfree induction earhook device enables a hearing-impaired individual with t-coil equipped hearing instruments to hear through a cell phone or audio device.

### *FM Devices*

Frequency-modulated (FM) systems refer to systems designed for individuals with hearing loss that broadcast signals from the talker to the listener via radio waves. Since the transmission mode of FM signals involves radio waves, the FCC has designated specific

frequency-bands for HAT use. FM systems operate at frequency bands ranging from 72 to 76 MHz and the 216 to 217 MHz (Bengtsson & Brunved, 2000). Recently, the higher frequency band of 216-217 MHz was designated primary status in the U.S., restricting the use of this higher frequency band to FM systems directly connected to hearing instruments (Launer, 2003).

While there are varying types of FM systems, they are all comprised of a transmitter and a receiver. In general, the transmitter is contained within the microphone that is used to pick up the source signal (i.e. the speaker's voice). The transmitter then sends the auditory signal via radio waves to a receiver. There are many receiver options available. For example, the Comfort Contego (Comfort Audio, Park Ridge, IL) is a self-contained FM system which may be worn in place of hearing instruments or may be interfaced with t-coil equipped hearing instrument utilizing a neckloop or other induction device. Other FM systems, such as the Phonak Zoomlink, are designed to interface with DAI. Both devices are described in more detail below.

#### Comfort Contego:

Figure 2 illustrates the Comfort Contego, a personal FM system designed to work independently or in conjunction with hearing instruments. It is comprised of two main components. The receiver, worn by the listener with hearing loss, contains a microphone, earphone connection (for headphones or neckloop) and volume control. During one-to-one conversations where both the listener and the talker are in close proximity to one another, the receiver may be used independently to facilitate conversation. In this particular situation, the listener will point the microphone of the receiver toward the sound source. The microphone will pick-up the conversation and route it to the headphones or to a neckloop in the event the user is wearing hearing instruments equipped with t-coils. In more challenging listening situations where the talker is located much further away from the listener (i.e. lecture situation), the

transmitter portion of the Comfort Contego, when worn by the talker, will wirelessly transmit the conversation to the receiver worn by the listener, enabling the listener to hear speech from distances up to 75 feet away at much more favorable SNRs.

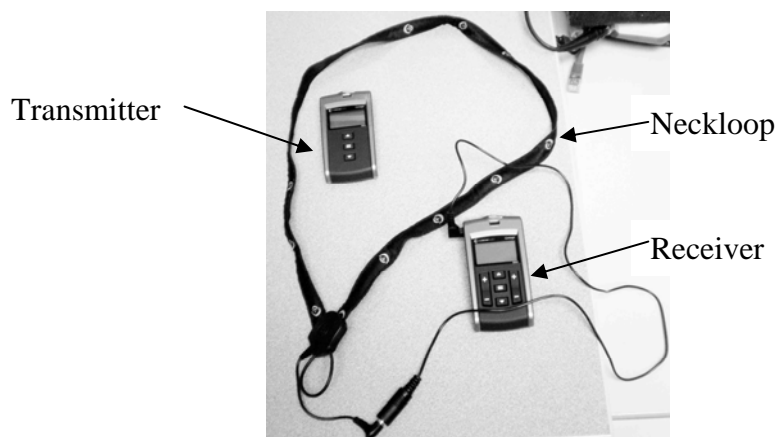


Figure 2: Comfort Contego consisting of a transmitter and receiver with an induction neckloop that transmits the signal electroacoustically via the t-coil of the hearing instruments.

#### Phonak Zoomlink:

The Phonak Zoomlink used in this study consists of the Zoomlink FM transmitter and MLxS FM receiver, shown in Figure 3. The Phonak Zoomlink is another variation of a personal FM system that is designed to be compatible with most hearing instruments, cochlear implants, and also Baha bone-anchored implants. The receiver portion of this system is coupled with the hearing instrument so that all components are on the ear(s) as it transmits the signal to the hearing instrument through DAI rather than a t-coil. The Micro MLxS receiver is capable of tuning to multiple frequencies and is programmable to modify frequency channels, amount of gain, and user data to best accommodate the wearer of the hearing instrument(s). In addition, the MLxS receiver has three switch positions (off, FM, or FM+M) to suit the input needs of the user. The Zoomlink transmitter, which is typically placed on the talker or near the sound source, has a built-in microphone and features three microphone modes to accommodate different listening situations. The omnidirectional mode is designed for situations such as quiet one-on-one

conversations, whereas the Zoom and SuperZoom modes are designed for more challenging listening situations when distance and/or noise competes with the talker's voice. The FM transmitter routes the intended speech signal via FM radio waves to the Micro MLxS receiver, and then to the hearing instrument(s) via DAI integrated in the audio shoe. The signal is then processed by the hearing instrument to deliver consistent sound quality that corresponds with the audiological programming of the individual's hearing instrument(s); thus, enabling the listener to hear the signal with better SNR through the hearing instrument's individualized amplification.

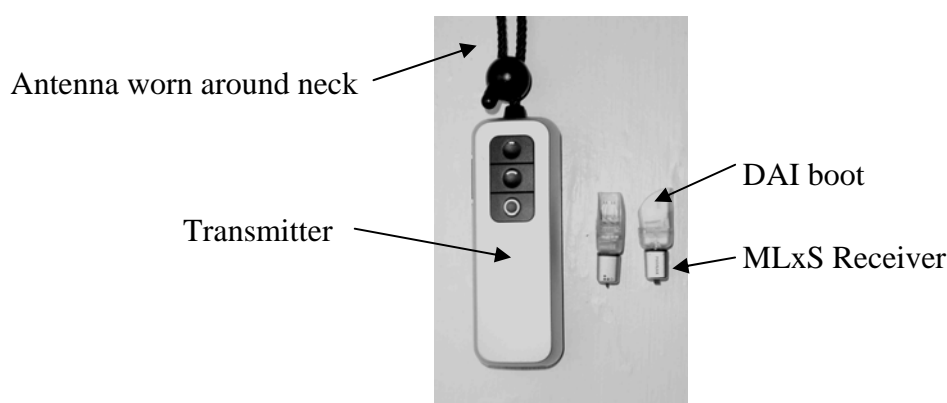


Figure 3: Phonak Zoomlink FM system: Phonak Zoomlink transmitter and Micro MLxS receiver that directs the signal wirelessly to the hearing instrument(s).

#### *HAT and Achievement of Accurate Word Recognition Scores*

Despite the availability of HAT, based on the finding of Yoder and Pratt (2005), only a portion of audiologists with hearing loss reported using various forms of HAT; the vast majority of this group also disclosed a lack of awareness with regard to the availability and/or the relevance of this technology to their daily professional requirements. HATs utilizing wireless FM and t-coil technologies have shown improvements in SNRs, which leads to improved speech intelligibility. Wireless microphones such as those of FM transmitters placed close to the mouth of the speaker pick up direct signals with +15-20 dB higher SNRs than that of a hearing instrument alone (Thibodeau, 2006). Various studies have also shown improved speech

recognition performance when utilizing FM technology. For example, Thibodeau (2006) compared sentence recognition abilities in adults while wearing hearing instruments only (HA) versus hearing instruments plus an FM system (HA+FM). With signal inputs controlled across listening conditions, each participant achieved higher sentence recognition scores in the HA+FM condition. Whereas the mean HA sentence recognition score for the group was 53%, the HA+FM condition yielded a mean score of 89%. On average, scores were improved by 36% in the HA+FM condition as compared to HA alone.

The findings summarized by Thibodeau (2006) were also corroborated in children. Pittman, Lewis, Hoover, and Steimachowicz (1999) compared word recognition scores in children with moderate to severe hearing loss obtained in noisy classroom environments. The average word recognition score obtained with hearing aids only was 55%; in contrast, the average word recognition score obtained in the HA+FM condition was 75%. On average, the scores were improved by 20% in the HA+FM condition as compared to the HA only condition. Unfortunately, there is a lack of clinical research available regarding the benefits of using HAT with hearing instruments to help audiologists with hearing loss to accurately score word recognition performances. In the absence of this research in the audiology literature, the primary goal of this study was to determine if audiologists with hearing loss can more accurately score word recognition abilities when utilizing HAT with current hearing instruments. Specifically, the current study was conducted to answer the following questions:

1. How effective are HAT in providing audiologists with hearing loss the ability to accurately measure word recognition scores as compared to relying on hearing instruments alone?



2. Of the three HAT technologies evaluated in this study, is one more effective in assisting audiologists with hearing loss in recognizing speech for purposes of accurately scoring word recognition performance?
3. Do users of HAT perceive these products as convenient and feasible?

## **Chapter II**

### **Methods**

#### **Participants**

An apriori estimation of subjects needed to achieve adequate power  $\geq .80$ , (Stevens, 1991) was calculated from data collected from the first ten subjects. Based on initial calculations, it was determined that data must minimally be collected from 17 subjects. Seventeen subjects with hearing loss and seventeen subjects with normal hearing were recruited for this study. For the group of participants with hearing loss, potential subjects previously diagnosed with bilateral, mild to severe symmetrical sensorineural hearing loss and fit binaurally with Widex hearing instruments were identified from Washington University Division of Adult Audiology hearing instrument database. Each potential subject was then contacted via telephone and informed by the author about the current study using a Human Research Protection Office (HRPO) approved script (See Appendix A). Consent forms, which were also approved by HRPO, described the study in more detail and were sent via US mail to those subjects who expressed an interest in participating in the study. Subjects were contacted via telephone within two weeks of mailing the consent form to schedule an appointment time for data collection. For the participants with normal hearing, subjects were recruited from the student population within the Program in Audiology and Communication Sciences (PACS) at Washington University School of Medicine (WUSM).

*Pre-experimental Audiometric Testing*

Each participant read and signed an informed consent approved by the Washington University's Human Research Protection Office (Appendix B). Pre-experimental audiometric testing was performed in the student Audiology laboratory at the PACS at WUSM to document hearing levels. The audiometric testing was performed in a sound-treated, single-walled audiometric test suite. For the subjects with hearing loss, the pre-experimental audiometric testing comprised of pure tone air and bone conduction audiometry. For the normal hearing group, the pre-experimental audiometric testing comprised of pure tone air conduction screening.

Each participant was seated in a cushioned chair in the sound-treated audiometric test booth at a right angle to the audiometer. Following instruction and headphone positioning, pure tone air conduction thresholds were obtained from both ears for subjects with hearing loss for the octave frequencies of 250 through 8000 Hz utilizing the modified Houghson-Westlake threshold technique (Carhart & Jerger, 1959). Following air conduction threshold testing, bone conduction thresholds were also obtained for the octave frequencies of 250 through 4000 Hz if changes in previously documented thresholds were present. Pure tone threshold was defined as the lowest intensity level for which the individual responded to a pure tone at least 50% of the time.

For the normal hearing group, pure tone air conduction screening was performed on both ears at 1000, 2000, and 4000 Hz utilizing a presentation level of 25 dB HL in accordance to screening standards established by the American Speech-Language-Hearing Association (ASHA, 1997).

### *Pre-experimental Audiometric Instrumentation*

Pure tone air conduction tests were performed with a calibrated GS1-61 audiometer connected to Telephonics TDH-50 earphones mounted on MX-41 cushions. Bone conduction tests were performed with the same calibrated audiometer utilizing standard bone conduction B-71 vibrator placed at the mastoid bone.

### *Criteria for Participant Inclusion*

In order for subjects with hearing loss to participate in this study, the following criteria were met: 1) bilateral sensorineural hearing loss ranging from mild to severe, 2) symmetrical audiometric configuration, defined by  $\leq 15$  dB interaural difference between the two ears at each octave frequency, 3) current bilateral users of either Widex Aikia, Diva, Inteo or Flash hearing instruments with a t-coil, 4) native English speaker, and 5) at least 18 years of age.

Subjects included in the normal hearing group were required to meet the following criteria: 1) pass an hearing screening by detecting air conduction pure tones of 25 dB HL at 1000, 2000, and 4000 Hz in both ears, 2) native English speaker, and 3) at least 18 years of age.

### *Pre-experimental Electroacoustic Analysis and T-coil Optimization of Hearing Instruments*

Each hearing instrument worn by subjects in the hearing-impaired group underwent an electroacoustic analysis to verify hearing instrument performance. In addition, t-coil settings were also measured and optimized as needed prior to proceeding with data collection. To accomplish both tasks, hearing instruments were first connected to a standard Hi-Pro interface box using appropriate Widex cables. The Hi-Pro interface was connected to a desktop computer configured with Noah (version 3.5.2). Using the Compass 4.1 Fitting Software (Widex, Inc.,

New York, NY), each hearing instrument's program(s) was assessed to identify the t-coil program. In addition, it was necessary to record walk-in Telegain Off-Set settings prior to programming any changes on initial walk-in program(s) to ensure re-programming of hearing instruments to initial walk-in levels at the conclusion of the data collection and prior to the subject leaving the test session.

Once walk-in Telegain Off-Set settings were recorded, hearing instruments were disconnected from the Hi-Pro box in preparation for electroacoustic analysis. In preparation for testing, the sound level chamber of the FONIX 6500-CX hearing aid test system (Frye Electronics, Inc., Tigard, OR) was leveled according to standard procedures outlined in the operator's manual. During leveling procedures, the microphone of the unit was placed on the left side of the sound chamber, with the microphone grill over the test point. The chamber was then closed with the lid latched and the leveling sequence was initiated by pressing the LEVEL button on the front panel of the FONIX unit. Following leveling, the microphone position was not changed to preserve the validity of the leveling procedure.

Following leveling procedures, hearing instruments were set to the default or primary program, coupled to a standard 2-cc coupler (HA-2) via an ear-level adapter with 0.4 inches (25 mm) of tubing between the nub of the ear-level adapter and the nub of the coupler adapter. The hearing instrument was placed in the sound chamber with the microphone of the hearing instrument at the test point in the chamber. The lid of the chamber was closed and an electroacoustic analysis was conducted via the ANSI S3.22-1996 automated test sequence whereby maximum Output Sound Pressure Level at 90 dB (OSPL90), high frequency (HF) average, HF average at full-on gain (50 dB), total harmonic distortion (THD) at 500, 800, and 1600 Hz, and equivalent input noise (EQ INP NOISE) measurements were obtained. While each

hearing instrument was assumed to fit appropriately if the subject was seen by the Division of Adult Audiology in the past year, an assessment of HF average and HF full-on gain was performed to document status of hearing instrument's microphone performance. In addition, the THD and EQ INP NOISE were recorded to ensure each subject's hearing instruments were within acceptable levels. Any hearing instrument with a THD value greater than 5% at either 500, 800 OR 1600 Hz was not to be included in the study, thereby disqualifying the subject from participating in this study. Fortunately, all hearing instruments had a THD value within acceptable levels and no subjects with hearing loss were disqualified.

Once an electroacoustic analysis of the hearing instruments were performed and the performance data was reviewed to ensure properly functioning device, the hearing instruments t-coil was optimized in preparation for study participation. With the hearing instrument residing in the sound chamber, the hearing instruments were manually switched from the default or primary program setting to the t-coil program. The hearing instrument t-coil responses were measured with a Telewand (Frye Electronics, Inc., Tigard, OR). This is a hand-held device that resembles a flat telephone receiver that plugs into the jack on the side of the sound chamber. The Telewand generates a 31.6-mA/m magnetic field representing or simulating the average strength of a hearing aid compatible telephone. With the Telewand positioned to the hearing instrument and kept parallel to the body of the BTE hearing instruments, minor adjustments were made in the Telewand position until the real-time read out generated on the monitor of the FONIX system indicated a consistent and optimal position. Optimal position was achieved when the HFA-SPLITS value was maximized and reliable. At this point, the Telewand was held in this optimal position, the CRT monitor of the FONIX was turned off, and a frequency sweep was completed to generate a Simulated Telephone Sensitivity (STS) SPLITS value.

Several different SPLITS measures are automatically calculated by the FONIX 6500 test system including the high frequency average (HFA)-SPLITS and the STS-SPLITS. These SPLITS measures represent the sound levels generated by the t-coil that are detected by the Telewand of the FONIX system. The HFA SPLITS response reflects the high frequency average (average at 1000, 1600, 2500 Hz) frequency response of the hearing instrument's t-coil, whereas the STS-SPLITS response is an absolute number that reflects the difference between the response of the hearing instrument's microphone and the response of the hearing instrument's t-coil (Frye, 2002). Specifically, the STS-SPLITS response is the mathematical difference between the HFA obtained at 90 dB SPL less 17 dB and the HFA-SPLITS response. For example, as shown in the Figure 4 below, for this particular hearing instrument, the FONIX generated an STS-SPLITS of -5.4 dB (A). This number may be calculated by subtracting 17 dB from the HF AVG (B) and then subtracting the HFA-SPLITS (C) from that number. The STS-SPLITS is the difference between output SPL resulting from a 60 dB acoustic input through the hearing instrument microphone and the output SPL resulting from an inductive input via the Telewand (Teder, 2003).

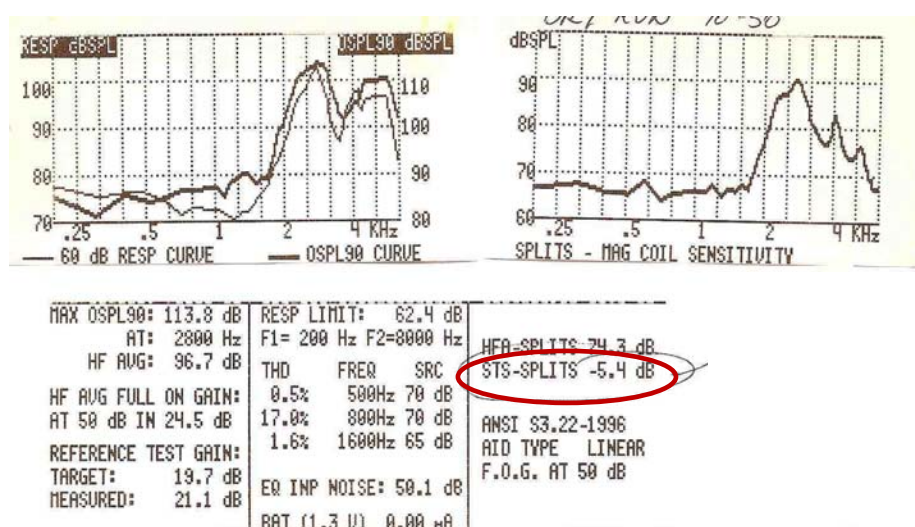


Figure 4: read out of hearing aid test measures for obtaining STS-SPLITS

To further illustrate, in the above example, -5.4 dB STS-SPLITS was calculated as follows:

$$\text{HF AVG} = 96.7 \text{ dB}$$

$$96.7 \text{ dB minus } 17 \text{ dB} = 79.7 \text{ dB}$$

$$79.7 \text{ dB minus } 74.3 \text{ dB (HFA-SPLITS)} = -5.4 \text{ dB}$$

When the STS-SPLITS reflect a positive number, it indicates that the average output of the hearing instrument's t-coil is greater than the output of the hearing instrument's microphone. For example, an STS-SPLITS response of +5.4 dB reflects that the output of the hearing instrument's t-coil is 5.4 dB greater than the output of the microphone. Conversely, an STS-SPLITS response of -11 dB indicates that the hearing instrument's t-coil is 11 dB poorer than the output of the hearing instrument's microphone.

Ideally, STS-SPLITS should be as close to zero as possible ( $\pm 3$  dB). This is similar to standards seen in other countries. The British, Swedish, and Australian governments specify that SPL of the t-coil with 31.6 mA/m field and microphone mode with 60 dB input be within  $\pm 5$  dB of each other. For this particular study, a more stringent range of variability in STS-SPLITS was applied. To control the t-coil setting for the subjects fit with hearing instruments, adjustments were made to each hearing instrument's Telegain Off-Set setting as needed, based on the STS SPLITS value. This was done by reconnecting hearing instruments to the Compass 4.1 fitting software, manually adjusting Telegain Off-Set values, and then once again completing STS-SPLITS measurements until a value of 0 ( $\pm 3$  dB SPL) were obtained. This indicated that the frequency response of the t-coil matched the frequency response of the microphone and



provided maximum benefit when using the t-coil position. This of course assumes that the microphone frequency response (the target) was programmed to a valid prescriptive target.

## **Experimental Procedures**

For purposes of this study, one normal hearing subject was paired with one subject with hearing loss, resulting in a subject pair that participated in the same data collection session. The subject from the hearing-impaired group was designated to play the role of the “audiologist” whereas the subject with normal hearing was assigned to serve the role of the “patient.” Subjects with hearing loss who were designated the role of “audiologist” were positioned outside of the audiometric booth in front of the GSI-61 audiometer. While this location represented the traditional location of the audiologist during testing procedures, at no time were these subjects required to manipulate audiometer settings. The investigator manipulated audiometer settings as needed to ensure speech material was delivered appropriately.

The subject with normal hearing was seated in a cushioned chair located inside the sound-treated booth by the investigator with the subject’s back oriented toward the subject serving as the audiologist. After instructing the normal hearing subject, the investigator positioned TDH-50 headphones over the ears of the normal hearing subject, exited the booth and closed the door.

### *Role of the Subject with Hearing Loss*

Subjects with hearing loss who served the role of “audiologist” were exposed to recorded word recognition test material and required to listen to the subsequent verbal responses provided by normal hearing subjects. Upon hearing the recorded target word followed by the immediate

verbal response of the normal hearing subject, the subject with hearing loss was required to make an immediate determination of whether or not the word presented by the normal hearing subject was repeated correctly or incorrectly. To keep accurate score, subjects with hearing loss were provided the actual list of 50 words that were presented on each word list with a blank space appearing next to each word. When words were perceived as repeated correctly, the blank space next to the target word was left blank; conversely, when words were perceived as repeated incorrectly, the subject with hearing loss placed a mark next to the word, indicating that the word was not repeated correctly. For example, if the word “BOAT” was correctly repeated by the normal hearing subject, the blank space next to the word “BOAT” on the answer sheet used by the subject with hearing loss was left blank. If the word “VINE” was incorrectly repeated by the normal hearing subject as “FINE”, the subject with the hearing loss indicated that the response was incorrect by writing in a line or an X mark.

#### *Listening Conditions for Subjects with Hearing Loss*

The ability for subjects with hearing loss to accurately determine correct versus incorrect responses to standardized word recognition tests was assessed under four different listening conditions: 1) hearing instruments only by listening to the talkback loudspeaker on the GSI-61 audiometer,, 2) hearing instruments interfaced with NoiZfree induction earhook, 3) hearing instruments interfaced with Comfort Contego and neckloop, and 4) hearing instruments interfaced with Phonak Zoomlink.

### 1. Hearing Instruments Only:

For this listening condition, subjects with hearing loss wore his/her bilateral Widex hearing instruments in the default or primary program using the microphone mode only. Verbal responses provided by normal hearing subjects while seated in the audiometric booth were routed from the talkback microphone to the external loudspeaker of the GSI-61 audiometer.

### 2. NoiZfree earhook:

For this listening condition, subjects with hearing loss wore his/her Widex bilateral hearing instruments with the instruments set to the t-coil only mode. The plug of a commercially available NoiZfree induction earhook (binaural) was customized and reconfigured by GSI so that the portion that typically plugs into a cell phone could be directly plugged into the back of the GSI-61 audiometer via the standard phone jack (Figure 5a). With the binaural NoiZfree induction earhook device positioned behind each subject's ear, verbal responses from the normal hearing subject were routed from the talkback microphone located in the soundbooth to the NoiZfree earhook via the GSI-61 audiometer (Figure 5b). With the hearing instruments set in the t-coil mode, responses were routed from the induction earhook directly to the subjects' hearing instruments.

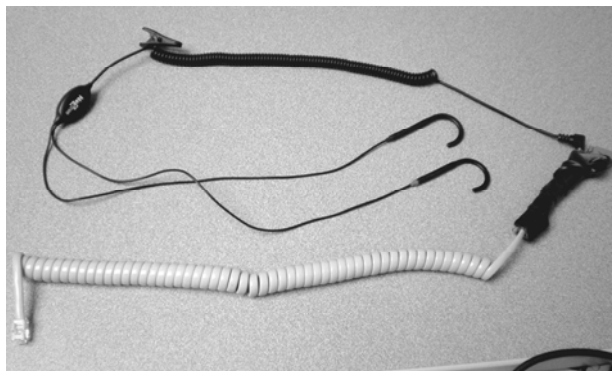


Figure 5a: Customized binaural NoiZfree induction earhook with telephone plug adapted for the audiometer.



Figure 5b: Configuration of bilateral NoiZfree earhook to audiometer during data collection.

### 3. Comfort Contego with neckloop:

For this listening condition, verbal responses generated by the normal hearing subject were routed to the t-coil of the other subject's hearing instruments via the Comfort Contego. Rather than relying on the talkback microphone located in the soundbooth, the FM transmitter portion of the Comfort Contego was positioned by the investigator such that the microphone of the transmitter was positioned 6 inches from the mouth of the normal hearing subject. The FM receiver portion of the Comfort Contego was interfaced with a neckloop which was positioned around the neck of subjects with hearing loss. Words repeated by the normal hearing subjects were picked up by the system's FM transmitter, wirelessly transmitted to and picked up by the FM receiver, and routed to the hearing instruments' t-coils via the neckloop. Figure 6 illustrated the configuration of the device during data collection for the subjects with hearing loss.

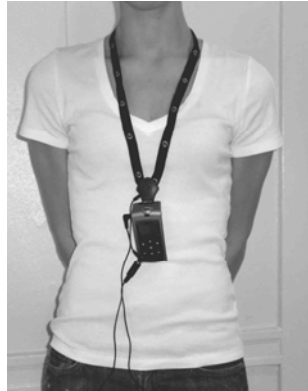


Figure 6: Comfort Contego FM receiver with neckloop positioned for each subject with hearing loss.

#### 4. Phonak Zoomlink and Micro MLxS receiver:

For this listening condition, verbal responses generated by the normal hearing subjects were routed to the hearing instruments worn by the subjects with hearing loss via the Phonak Zoomlink. Rather than relying on the talkback microphone located in the sound booth, the FM transmitter portion of the Phonak Zoomlink was positioned by the investigator such that the microphone of the transmitter was positioned 6 inches from the mouth of the normal hearing subject. The FM receiver portion (Micro MLxS receiver) of the Phonak Zoomlink interfaced with hearing instruments via direct audio input (DAI). Words repeated by the normal hearing subjects were picked up by the transmitter, wirelessly transmitted to the receiver, and then routed directly to the amplifier of the hearing instruments. Figure 7 shows the configuration used with each subject with hearing loss.



Figure 7: Configuration of the Phonak receiver worn by subjects with hearing loss. FM receiver was connected to both hearing instruments via an audio shoe with direct audio input (DAI).

### *Role of the Subject with Normal Hearing*

To play the role of the “patient”, subjects with normal hearing were required to provide a verbal response immediately following the presentation of each recorded target word from the standardized recording. Four different word lists comprised of 50 words were presented to the normal hearing subjects. Unbeknownst to the other subject, for each 50 word list, the normal hearing subject serving as “patient” was provided with a corresponding 50 word answer list of pre-fabricated responses, which included responses that were intentionally incorrect. Normal hearing subjects were instructed to repeat the words on the list rather than the words that they heard via headphones. For example, when subjects heard the word “CAT” and the response on their sheet indicated that the word was “CAT”, the subject provided the word “CAT” as their verbal response. When subjects heard the word “DOG” but the answer on their sheet was “FOG”, the subject with normal hearing, despite accurately hearing “DOG” provided the word “FOG” as their verbal response. Each 50-word answer lists contained anywhere from 5 to 15 foils or intentional errors.

*Speech Material*

Word recognition testing was performed utilizing the Northwestern University Auditory Test No. 6 (Form A, lists 1-4) recording utilizing a female talker. The speech material was played by a Panasonic CD and routed to the patient's headphones via a GSI-61 audiometer at a 40 dB HL presentation level. In every test condition, words were presented to the normal hearing subject's right ear only.

**Word Recognition Score Testing Procedures**

To control for order effects and duration effects, the order of listening conditions for each subject was randomly assigned. In addition, the sequence of the four word recognition lists was similarly counterbalanced to control for practice effects. Prior to initiating word recognition testing, the recorded test was calibrated using the calibration tone. Before commencing with testing, a script of the rainbow passage was provided to the subject with normal hearing to read aloud. This enabled the primary author to set the most intelligible level (MIL) for the subjects with hearing loss prior to each listening condition and manipulating audiometer dials as needed. In addition, this procedure allowed for adjustments to be made to the hearing instruments (i.e. change in volume) or HAT (change in volume). Once these levels were established, the subject could not adjust the volume of his or her hearing instruments or the HAT device.

*Calculation of Scores*

For data collection, overall scores were computed. Overall scores referred to the number of words that the subject with hearing loss correctly identified as both correct and incorrect. For a 50-word list, each response that was correctly perceived by the subject with hearing loss was

assigned a 2% value. For example, if the word “BOAT” was presented to the normal hearing subject, verbally repeated correctly as “BOAT” by the normal hearing subject, and then accurately perceived by the subject with hearing loss as “BOAT”, a 2% value was assigned to the overall score. Similarly, if the word “VINE” was presented to the normal hearing subject, intentionally repeated incorrectly as “FINE” by the normal hearing subject, and then accurately perceived by the subject with hearing loss as an incorrect response, a 2% value was also assigned to the overall score. In contrast, if a the subject with hearing loss incorrectly perceived the verbal responses provided by the normal hearing subjects, no value was assigned to the overall score. For example, if subjects with normal hearing were presented the word “DOG”, purposely provided the verbal response “FOG” as dictated by the script, yet the subject with hearing loss perceived that the response was indeed “DOG”, the perception on the part of the individual with hearing loss was considered inaccurate. In this case, no value was assigned to this instance. Since each word list was comprised of 50 words and the value of each correct perceived response by the subject with hearing loss was assigned a 2% value, the highest obtainable maximum score was 100%.

## **Questionnaire**

Subjects with hearing loss participated in a paper and pencil survey comprised of ten questions addressing previous use of HAT and subjective impressions of sound quality, speech recognition, convenience, and ease of use among the various hearing assistance technologies incorporated during word recognition testing. A copy of the survey is found in Appendix C.



## **Chapter III**

### **Results**

Several statistical models of varying complexity were used to analyze the performance data obtained during word recognition testing using SigmaPlot 11 software and G power \*3 software.

#### **Subject Demographics**

Twelve males (70%) and five females (30%) comprised the group of subjects with hearing loss and ranged in age from 59 to 91 years of age with a mean age of 72.9 years (SD=11.0 years). Of these seventeen subjects, one (5%) was fit with a Diva instrument, 13 (77%) with the Inteo, and three (18%) with the Flash. All subjects with hearing loss had worn their current amplification for at least four weeks with duration of wearing experience ranging from as little as 12 weeks to 2.3 years (mean=1.6 years, SD=2.2 years). In addition, all subjects with hearing loss were native English speaking adults with no reported educational background in Audiology. Subjects in the normal hearing group consisted of 17 females (100%) between the ages of 22-29 years with a mean age of 24.3 years (SD=1.6 years). Subjects in the normal hearing group were native English-speakers and had educational background in the field of Audiology.

#### **Overall Scores**

Overall scores were calculated independently for each of the seventeen subjects with hearing loss for the four listening conditions that included: 1) hearing instruments only, 2)

hearing instruments and NoiZfree earhook, 3) hearing instruments and the Comfort Contego, and 4) hearing instruments and the Phonak Zoomlink. The mean and standard deviation of overall scores obtained from the 17 subjects with hearing loss for the four treatment conditions are reported in Table 1. The demographic data reveals poorest performance with hearing instrument only, followed by incremental improvement in mean overall scores with the NoiZfree earhook, Phonak Zoomlink, and the Comfort Contego, respectively.

TABLE 1: Mean overall scores, standard deviations and 95% confidence interval between means of subjects with hearing loss as a group obtained in four different listening conditions.

<b>Treatment Condition</b>	<b>Mean</b>	<b>Standard Deviation (%)</b>	<b>95% CI of between means (%)</b>
<b>Hearing instruments only</b>	<b>82.2%</b>	<b>4.9</b>	<b>2.3</b>
<b>Comfort Contego and neckloop</b>	<b>90.2%</b>	<b>6.1</b>	<b>2.9</b>
<b>Phonak Zoomlink via DAI</b>	<b>88.8%</b>	<b>7.8</b>	<b>3.7</b>
<b>NoiZfree earhooks</b>	<b>88.7%</b>	<b>5.1</b>	<b>2.4</b>

A one-way analysis of variance (ANOVA) revealed statistically significant performance differences between overall scores across the four listening conditions ( $dF = 3$ ,  $F = 6.045$ ,  $p < 0.001$ ). A post-hoc Tukey HSD revealed:

1. the mean overall scores obtained with the hearing instruments interfaced with the NoiZfree earhooks were significantly different (6.5% difference) than mean overall scores obtained with the hearing instruments only ( $p < 0.05$ )
2. the mean overall scores obtained with the hearing instruments interfaced with the Contego FM system/neckloop were significantly different (8.0% difference) than mean overall scores obtained with the hearing instruments only ( $p < 0.05$ )

- the mean overall scores obtained with the hearing instruments interfaced with the Phonak Zoomlink were significantly different (6.6% difference) than mean overall scores obtained with the hearing instruments only ( $p < 0.05$ )

With reference to the post-hoc Tukey HSD results, as shown in Figure 8, examination of the demographic data shows that the highest mean overall score as obtained in the listening condition whereby subjects interfaced their hearing instruments with the Comfort Contego and neckloop (90.2%), followed by the Phonak Zoomlink (88.8%), and the NoiZfree earhooks (88.7%).

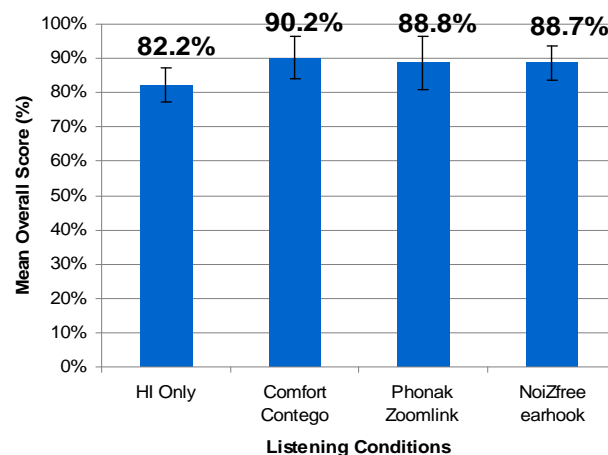


Figure 8: Mean overall scores obtained for the four listening conditions.

### Post Hoc Sample Size Calculation and Cohen's D

A post hoc calculation was performed based upon the resulting mean and standard deviations using G Power \*3 software and the results indicated that a subject sample size of 17 would be required. A Cohen's D was also calculated based upon the reported means and standard deviations and the resulting Cohen's D of 0.90 revealed that the effect size between the three HAT devices and the hearing instrument only condition was very clinically significant.

## Questionnaire Results

All seventeen subjects from the hearing loss group were provided with an informal ten item questionnaire addressing previous use of HAT and subjective impressions of HAT sound quality, speech recognition, convenience and ease of use during experimental procedures. The results of the questionnaire appear in Appendix D with specific results to each question outlined in more detail in the section below.

### *General HAT use History and overall experience*

General information regarding history of HAT use prior to this study and overall impression of HAT benefit experienced during this study were collected from the 17 subjects with hearing loss. As shown in Figure 9, an overwhelming majority of subjects with hearing loss (N=15, 88.3%) reported never using HAT in conjunction with their hearing instruments. Of the two subjects (11.8%) who reported using HAT in the past, one subject reported using an amplified telephone; whereas the other subject indicated the use of a TV listening device.

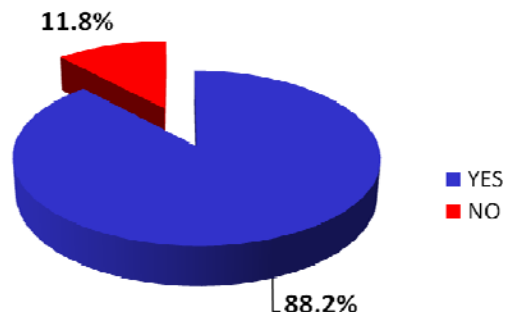


Figure 9: Subject history of previous use of HAT with their hearing instruments.

Figure 10 illustrates the reported general benefit of using HAT. Specifically, subjects were asked whether or not one or more of the devices helped with speech recognition as compared to using their hearing instruments only. As illustrated in Figure 10, an overwhelming majority of (N=15, 88.3%) reported that at least one of the HAT devices helped in perceived speech recognition than use of hearing instruments alone. A small percentage of the subjects (N=2, 11.8%) reported that none of the technologies were helpful.

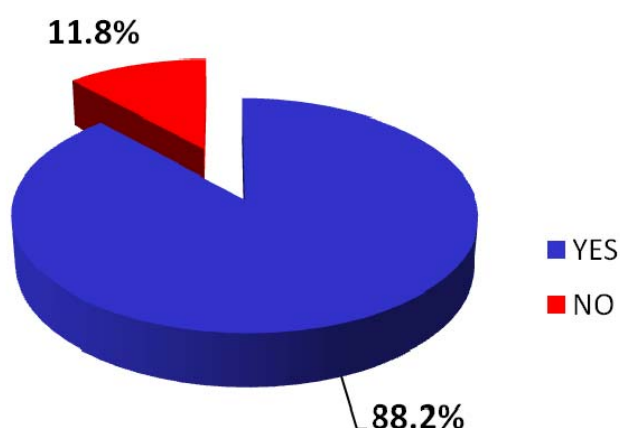


Figure 10: General benefit reported using HAT

#### *Perception of Speech Recognition and HAT Sound Quality (Questions 3 and 4)*

The remaining eight survey questions are based on responses from 15 of the 17 subjects who indicated improved speech recognition with at least one of the HATs as compared to their hearing instruments alone. As shown in Figure 11, more than half of the respondents (8/15, 53.4%) perceived understanding of speech to be best with the Phonak Zoomlink. The remaining subjects reported understanding speech best with either the Comfort Contego (N=5, 33.4%) or the NoiZfree earhooks (N=2, 13.4%). None of the respondents indicated understanding speech better with hearing instruments only. In terms of overall sound quality, the same results were

evident as shown in Figure 12. Slightly more than half of the subjects with hearing loss (8/15, 53.4%) reported best sound quality with the Phonak Zoomlink while the remaining 33.4% (N=5) and 13.4% (N=2) indicated best sound quality with the Comfort Contego and NoiZfree earhooks, respectively. None of the respondents indicated preferred sound quality with hearing instruments only.

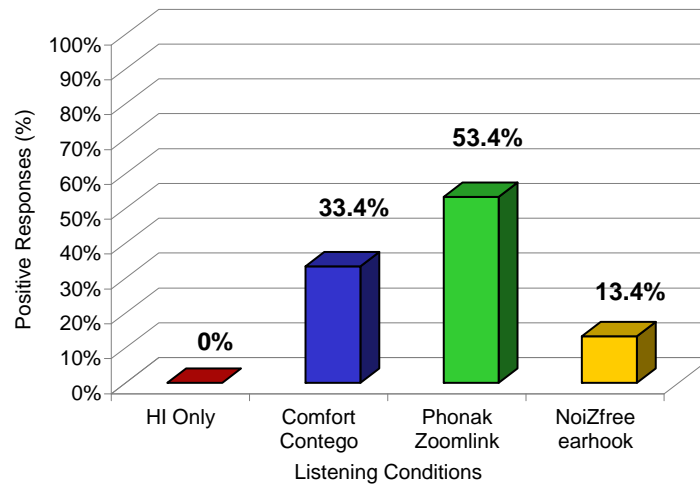


Figure 11: Percent of subject reporting best perceived speech recognition when using one four HAT technologies.

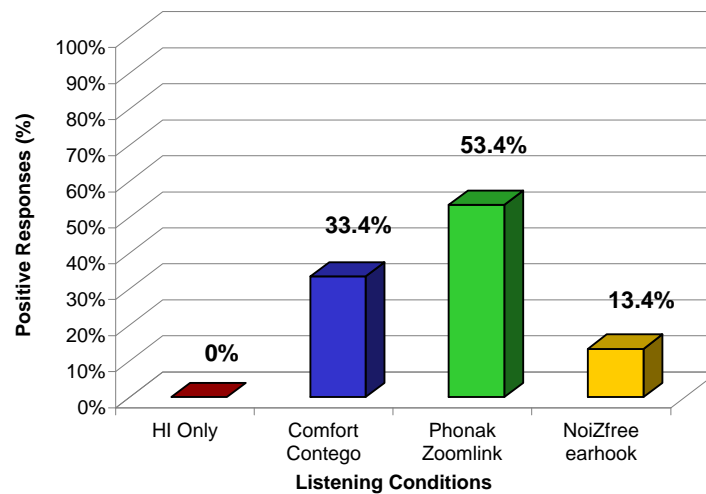


Figure 12: Best perceived sound quality as a function of HAT devices.

### *Perceived Noise with HAT (Question 5)*

Most subjects with hearing loss did not encounter distracting or unwanted noise while using each HAT (11/15 or 73.2%). As shown in Figure 13, four subjects with hearing loss (4/15, total of 26.7%) perceived that at least one of the HATs resulted in distracting or unwanted noise, with each subject reporting complaints with different devices. Specifically, one subject reported experiencing noise when using his/her hearing instruments only. In contrast, a second subject reported noise while using the Comfort Contego, whereas a third and fourth subject reported experiencing noise while using the Phonak Zoomlink and NoiZfree earhook, respectively.

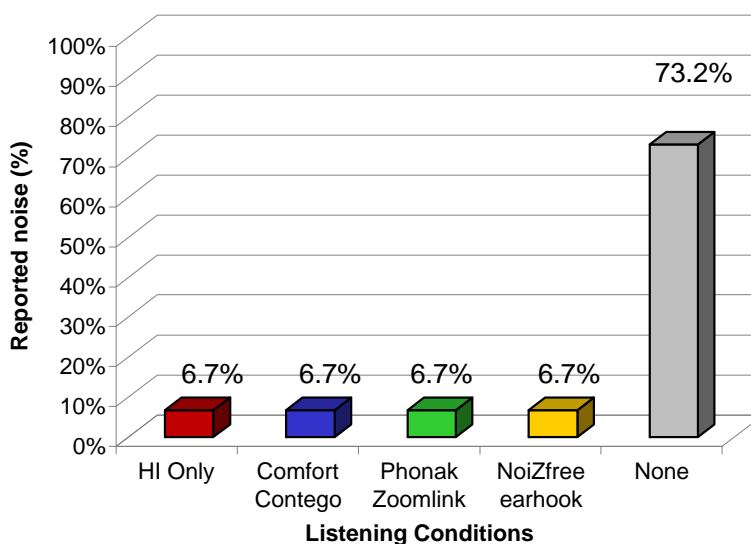


Figure 13: Percentage of subjects reporting noise with hearing instruments alone or the three HAT devices.

### *Preferred HAT Device (Question 6)*

Figure 14 illustrates the preferred HAT device as reported by the subjects with hearing loss. More than half of the subjects preferred the Phonak Zoomlink (8/15 or 53.4%) in terms of understanding speech. Five subjects (5/15, 33.4%) preferred the Comfort Contego, one subject

(1/15, 6.6%) preferred the NoiZfree earhooks, whereas one subject (1/15, 6.6%) preferred to use his hearing instruments alone.

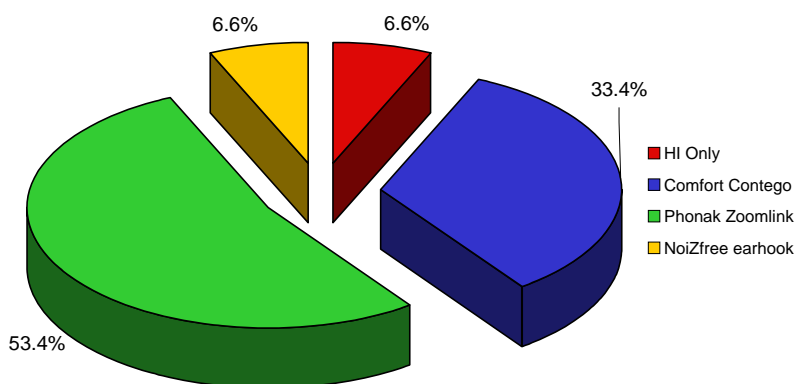


Figure 14: Percent of subjects with hearing loss reporting their preferred HAT device

#### *Ease of Adjustment (Question 7)*

As shown in Figure 15, almost half of the subjects with hearing loss reported ease of adjusting the volume to be best with either the Comfort Contego (6/15, 40%) or Phonak Zoomlink (6/15, 40%). One subject preferred the NoiZfree earhook (6.6%). Two subjects (13.4%) felt they could not accurately judge the ease of adjusting the volume level and elected not to provide an answer to this question.

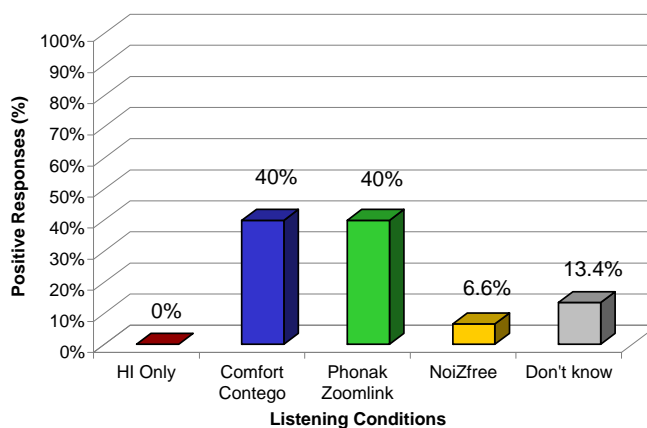


Figure 15: Perceived ease of device adjustment across the four listening conditions.



*Perceived Time Investment for Configuring Listening Conditions (Question 8)*

Subjects were asked to rank the time that was invested in preparing each HAT device to the optimal position before beginning each listening condition. The results are shown in Table 2. Overall, most subjects (11/15 or 73.4%) perceived using their hearing instruments alone to take the least amount of time to prepare, while mixed answers to this question resulted when asked which HAT device took the most time in preparing the listening condition. In terms of which of three HAT devices required the least amount of time, most subjects answered that configuration for the Phonak Zoomlink took the least amount of time.

TABLE 2: Perceived time investment for preparing for each listening condition.

	<b>Phonak Zoomlink</b>	<b>Comfort Contego</b>	<b>NoiZfree earhooks</b>	<b>HI only</b>
<b>Least time (1)</b>	<b>20%</b> <b>(3/15)</b>	<b>6.6%</b> <b>(1/15)</b>	<b>0%</b> <b>(0/15)</b>	<b>73.4%</b> <b>(11/15)</b>
<b>(2)</b>	<b>35.7%</b> <b>(5/14)</b>	<b>42.9%</b> <b>(6/14)</b>	<b>2.1%</b> <b>(3/14)</b>	<b>0%</b> <b>(0/15)</b>
<b>(3)</b>	<b>21.4%</b> <b>(3/14)</b>	<b>35.7%</b> <b>(5/14)</b>	<b>35.7%</b> <b>(5/14)</b>	<b>7.1%</b> <b>(1/14)</b>
<b>Most time (4)</b>	<b>21.4%</b> <b>(3/14)</b>	<b>14.3%</b> <b>(2/14)</b>	<b>42.9%</b> <b>(6/14)</b>	<b>21.4%</b> <b>(3/14)</b>

*Perceived Convenience of Listening Condition (Question 9)*

With regard to the issue of convenience, as shown in Figure 16, most subjects reported the Phonak Zoomlink (6/15 or 40%) or hearing instruments only (6/15 or 40%) were most convenient. Three subjects (3/15 or 20%) indicated the Comfort Contego was the most convenient configuration compared to the other three listening conditions. None perceived the NoiZfree earhooks to be most convenient.

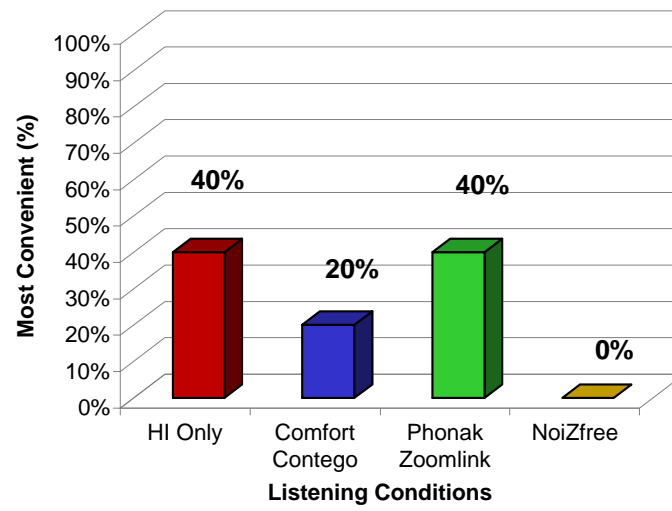


Figure 16: Perceived convenience of use across the four listening conditions.

## **CHAPTER IV**

### **Discussion & Conclusion**

The purpose of this study was to obtain insight as to whether HAT can assist audiologists with hearing loss to more accurately hear responses of patients during word recognition testing and hence, lead to more accurate word recognition score calculations when compared to using their hearing instruments only. To achieve this goal, 17 subjects with hearing loss were recruited to play the role of “audiologists” in four different listening conditions. Their task was to identify whether or not the verbal answers provided in response to a standardized, recorded word recognition test was correct or incorrect. Unbeknownst to the subjects with hearing loss, normal hearing subjects were prompted to intentionally provide erroneous answers. The ability for the subjects with hearing loss to accurately identify both correct and intentionally incorrect words was reflected in a calculated mean overall score. The higher the mean overall score, the more accurate the subjects with hearing loss were at perceiving verbal responses of the normal hearing subject correctly.

### **Subject Recruitment**

In terms of subject recruitment, this study was designed to recruit two groups of adult subjects: 1) Individuals previously diagnosed with symmetrical, mild to severe sensorineural hearing loss bilaterally who were current, bilateral users of specific product lines of Widex hearing instruments, and 2) Individuals with normal hearing. With regard to the subjects with hearing loss, audiometric testing was performed to confirm current hearing status to ensure that subjects met inclusion criteria. Initially, only those with symmetrical sensorineural hearing loss,

defined as the absence of a greater than 15 dB interaural difference at any one audiometric frequency, were included. However, due to the limited number of individuals from the Washington University Division of Adult Audiology database who fully met the inclusion criteria, three additional subjects with asymmetrical hearing losses with similar configurations were included. Specifically, the three subjects (HI04, HI11, and HI15) presented with interaural differences greater than 15 dB, but met all other inclusion criteria mentioned. The asymmetry between ears had previously been documented, but was of a mild sloping to severe configuration bilaterally and also sensorineural in nature; thus, having similar hearing loss as the group with symmetrical hearing loss. The asymmetry was present in the lower frequencies (250, 500, and/or 1000 Hz) ranging from 20-40 dB. One subject (HI04) only had interaural differences of 20 dB at 250 and 500 Hz, while the other two subjects had interaural differences of 30-40 dB at 250 and 500 Hz, and 20-25 dB at 1000 Hz. Interestingly, all three subjects had better hearing thresholds in the right ear.

Shown in the right graph of Figure 17 are the average air conduction thresholds, since all hearing losses were sensorineural in nature, of the three subjects with asymmetrical hearing loss. For the subjects with asymmetrical hearing loss, hearing thresholds in the right ear were, on average, better in the low frequencies than the subjects in the symmetrical hearing loss group shown in the left graph of Figure 17, while the hearing thresholds in the left ears of the asymmetrical hearing loss group were poorer than those of subjects with symmetrical hearing loss. Thus, when averaged between the ears, the asymmetry seen between the ears of the three subjects with asymmetrical hearing loss were of similar configuration and degree of those with symmetrical hearing loss. Also, when compared to previously documented audiometric results, no significant changes were observed for any of the 17 subjects.

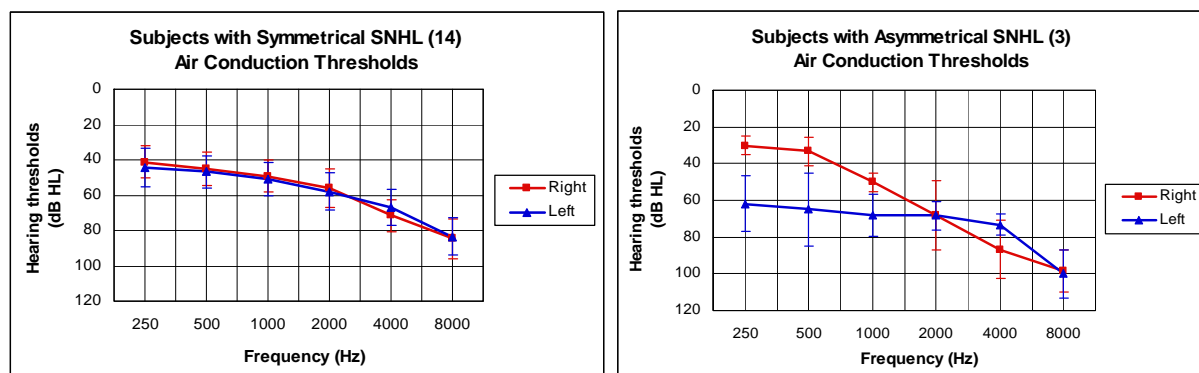


Figure 17: Mean air conduction thresholds for subjects with symmetrical sensorineural hearing loss (SNHL) at the left, and mean air conduction thresholds for subjects with asymmetrical SNHL at the right.

In terms of performance and subjective findings, the three subjects with asymmetrical hearing loss achieved scores that resembled those of the subjects of symmetrical hearing loss, obtaining better scores in one or more HAT conditions than the hearing instruments only condition. Mean overall scores obtained for these subjects were 93.3% for the Comfort Contego, 90.7% for the Phonak Zoomlink, 86.0% for the NoiZfree earhooks, and 82.0% for hearing instruments only. Subjectively, all three subjects reported benefit using one or more of the HAT. Two of the three subjects preferred the Phonak Zoomlink, while one preferred the Comfort Contego for better speech understanding and sound quality. In fact, one subject (HI15) reported that words were “just not as clear using only her hearing instruments” when performing the listening task. With these considerations in mind, including the subjects with asymmetrical hearing loss had little effect on the overall results of the study.

### Subject Demographics

Demographic data regarding age and gender was collected for the two groups. For the group with hearing loss, the majority of subjects were male (70%). In contrast, the normal hearing group was comprised of all females (17/17 or 100%). With regard to the later group, this

finding was not surprising and generally expected based on current gender distribution of students enrolled within the Program of Audiology and Communication Sciences at Washington University School of Medicine. Having the normal hearing group comprised of only females was not considered a risk to external validity; in fact, it most likely helped control any possible variability in speech recognition that could have otherwise occurred in the event the normal hearing group included a mix of male and female subjects. The task for the group with hearing loss was to discriminate whether the verbal responses of the normal hearing subjects was same word or different than the word presented via the CD recording (correct or incorrect). As reported by Wilson and colleagues (1990), even when male and female voices are recorded at 0 VU, the intensity of the female voice must be raised at least 10 dB in quite to approximate performance-intensity functions comparable to that of males. Due to spectral differences between male and female talkers, listening to verbal responses from female subjects is most likely a more difficult task for those with high frequency hearing loss and thus more sensitive to hearing difficulties, since females tend to have higher pitched voices than males. With all the normal hearing subjects being female, the level of task difficulty for the subjects with hearing loss was arguably controlled.

With regard to age, any variability that may have existed in the normal hearing group is moot since their role was to repeat monosyllabic words. This task was not affected by factors including age. In terms of the subjects with hearing loss, the age range of this group was quite extensive, ranging over a span of 30 years (59-91 years of age). Although age was not controlled for in subject inclusion criteria, the average age of the group with hearing loss was greater than the average age of practicing audiologists. Aging causes changes in auditory and non-auditory processing abilities, as well as cognitive function that can affect speech recognition. Not only do

changes occur in peripheral auditory function (i.e. reduced auditory sensitivity and distortion in cochlear mechanics), but age-related changes can also occur in central auditory processing, impacting speech understanding and thus word recognition scores (Vaughan et al., 2008). In addition, cognitive changes, specifically working memory and processing speed, have been reported to be involved in speech recognition difficulties in older adults (Wingfield et al., 1988). Compared to younger individuals who may currently practice in the field of Audiology, subjects with hearing loss in this study may have inherent age-related issues beyond sensorineural impairment that may affect their word recognition abilities. No trends were seen between age and recognition abilities, (aka: overall scores in this study), but the age range of this group are of an older age generally known to have age-related issues.

### **Statistical versus Clinical Significance of Overall Mean Scores**

A primary focus of this investigation was to compare the mean overall scores between four different listening conditions to determine whether a specific listening condition was more conducive to facilitating accurate recognition of responses to conventional word recognition tests. An ANOVA revealed better or higher mean overall scores across three listening conditions utilizing some type of HAT as compared to using hearing instruments alone at levels considered statistically significant. Specifically, as a group, the most accurate mean overall scores were obtained by those subjects with hearing loss when using their hearing instruments with the Comfort Contego, followed by equivalent performance with the Phonak Zoomlink and NoiZfree earhook, but no overall difference was found between the three HAT devices. In other words, individuals with hearing loss performed statistically significantly better when pairing their hearing instrument with HAT as compared to using their hearing instrument only. The findings

of this study are relevant to practicing audiologists and AuD student with hearing loss as it sheds some insight toward clinical practice considerations and potential accommodations that may be required or helpful during word recognition testing procedures.

In the presence of statistically significant findings, the question of clinical significance represents a more critical issue. Despite a statistical difference between several of the group means, the more pertinent question is whether the difference between the group means translates to clinically significant findings. For example, the highest mean overall score was 90.2%, obtained with the hearing instrument and Comfort Contego combination. In contrast, the lowest or poorest average mean overall score was 82.2%, acquired with hearing instruments only. The question, therefore, remains whether this 8% difference is large enough to equate to any clinical significance.

### **Interpretation of Word Recognition Scores Obtained by Group with Hearing Loss**

During conventional audiometric testing, word recognition scores are usually qualified as excellent, good, fair, or poor based on percentages (Berger, 1978). When placed within the context of audiometric findings, including degree and configuration of the hearing loss, the information may be used to assess what phonetically-balanced words were heard or not heard. From this perspective, one could consider the mean overall score of 90.2% obtained with the Comfort Contego as excellent performance compared to good performance of 82.2% obtained with the hearing instruments alone. Certainly, excellent is better than good; however, this approach is not very useful for several reasons. First, when qualifying performance as excellent versus good, it is not clear what this actually means. Second, the purpose of this study did not involve obtaining word recognition scores in the conventional sense; rather, the intent was to test



the ability of subjects with hearing loss to recognize words as being correct or incorrect under four different aided conditions to determine if a specific condition resulted in a more accurate outcome than another. Therefore, the interpretation of group performance may be subjectively assessed by comparing absolute group means to determine the presence of clinical significance.

The group means obtained in the four different listening conditions may be treated as four word recognition test performance scores obtained from the same patient. In clinical practice, scores obtained on conventional word recognition tests are associated with some degree of variability within the same subject. Thornton and Raffin (1978) demonstrated this variability and subsequently compiled a critical differences table for speech recognition scores which reflect acceptable ranges in word recognition scores attributed to test-retest variability. A table adapted from Thornton and Raffin (1978) addressing critical differences for speech recognition scores utilizing 50-word lists is shown below (Table 3). In using the table, if an initial test score on a 50-item word list was 88%, it would take a score of less than 74% or more than 96% to be considered clinically deviant at the 95% confidence level. In other words, in the presence of an 88% word recognition score, a 95% probability exists that the same subject, upon repeat testing, will score between 74 and 96%.

Table 3: Adapted from Thornton and Raffin (1978). Critical difference ranges for word recognition scores ( $p > 0.05$ ).

<b>Initial Word Recognition Score</b>	<b>50-item word list range of score values</b>	<b>Initial Word Recognition Score</b>	<b>50-item word list range of score values</b>
<b>100%</b>	<b>96-100%</b>	<b>90%</b>	<b>76-98%</b>
<b>98%</b>	<b>90-100%</b>	<b>88%</b>	<b>74-96%</b>
<b>96%</b>	<b>86-100%</b>	<b>86%</b>	<b>70-96%</b>
<b>94%</b>	<b>82-98%</b>	<b>84%</b>	<b>68-94%</b>
<b>92%</b>	<b>78-98%</b>	<b>82%</b>	<b>66-94%</b>

Applying Table 3 to this particular study, the comparison of the two most disparate overall group means obtained among the four listening conditions may provide insight as to whether or not the performances in the two listening conditions are sufficiently different to present any clinical significance. For instance, the best mean overall score was obtained with the Comfort Contego and hearing instruments condition, yielding an average group score of 90.2%, while the lowest or poorest mean overall score was obtained in the hearing instruments alone condition, resulting in an average group score of 82.2%. According to Table 3, the difference between the two listening condition extremes falls within the 95% critical intervals. The normal test-retest variability for an original word recognition score of 90.2% on a 50-item word list will range from 76 to 98%. Since the performance in the hearing instruments alone condition falls within this 95% confidence interval, despite the presence of statistical significance, the difference in group performances between the Comfort Contego and hearing instruments condition versus hearing instruments alone condition did not yield any clinical significance. Since the group means between the remaining listening conditions is smaller, as shown in Table 4 below, none of the listening conditions resulted in findings considered clinically significant. In other words, a hearing-impaired listener can recognize verbal responses of subjects within acceptable ranges of variability when using digital hearing instruments alone as compared to when using hearing instruments in combination with the HAT devices utilized in this study.

Table 4: comparison of mean overall score of three HAT listening conditions compared to hearing instrument alone with associated critical difference ranges.

	Mean Overall Score	Mean Overall Score with hearing instrument only	Critical difference range at $p>0.05$
<b>Comfort Contego</b>	90.2%	82.2%	76-98%
<b>Phonak Zoomlink</b>	88.8%	82.2%	~74-96%
<b>NoiZfree Earhooks</b>	88.7%	82.2%	~74-96%

### **Perceived Sound Quality**

While the findings cannot be quantified, qualitative feedback based on answers to the informal questionnaire clearly indicated that most subjects with hearing loss subjectively found the conditions utilizing HAT in addition to their hearing instruments to be beneficial in terms of speech recognition and sound quality. Even though overall mean scores utilizing the HAT devices did not result in clinically relevant improvements in word recognition abilities, the perceived benefits of integrating this technology into clinical practice should not be ignored. Several subjects commented that one or more of the HAT devices had better sound quality than using their hearing instruments alone. Throughout the course of the day, this perceived benefit may play a critical role in reducing stress and fatigue on the part of the audiologist with hearing loss in performing his or her clinical duties.

### **Perceived Ease of Use of Utilizing HAT**

In terms of perceived ease of incorporating HAT into the testing situations, a portion of the informal questionnaire specifically addressed issues pertaining to convenience of product use. This is particularly important in those instances where patient loads require clinicians to work quickly; if incorporating certain technologies is viewed as tedious, clinicians may refrain from utilizing HAT devices despite any objective or subjective benefit. In general, the majority of subjects perceived the Phonak Zoomlink or hearing instruments alone as most convenient. Interestingly, while the hearing instruments alone condition did not require any significant adjustment, the Phonak Zoomlink did involve more preparation time. The choice of an HAT as “most convenient” does not reflect current trends in audiology clinics where individuals who could benefit from HAT reject purchasing and using them because of factors such as cost,

cosmetics, and care. However, the subjects who perceived an HAT, such as the Phonak Zoomlink, to be convenient may have been considering the subjective benefit of better speech recognition, and not factors of cost and care as patients in an audiology clinic would have. Not surprisingly though, most (73.4%) of the subjects indicated that hearing instruments alone required the least time to prepare.

Unfortunately, the format of the questionnaire created difficulty in having subjects consistently answer questions addressing ease of use and convenience of the HAT devices. For example, the ease of adjusting volume on various products was not consistently answered initially by subjects. Two subjects did not answer the question and it was necessary to prompt and encourage other subjects to answer the question. While most subjects (80%) rated the Comfort Contego and the Phonak Zoomlink devices to be easiest to adjust volume, it may be that the additional prompting and encouragement forced an answer that may not be truly indicative of the perceptions of the entire group. Judging the time invested in preparing for each listening condition was also challenging for subjects since they did not consciously track configuration times. For that reason, it remains unclear as to which HAT devices were perceived as requiring less configuration time although both the Comfort Contego and Phonak Zoomlink were both judged to be the least time consuming after the hearing instruments alone condition.

### **Perceived Noise Using HAT**

Interfering noise can occur using HAT due to the additional connection to hearing instruments. Devices with t-coils utilize a magnetic field that can also be found in other objects, such as fluorescent lights, electric motors, television sets, and computer screens. These interfering magnetic fields cause the t-coil to pick up a magnetic signal that often produces a low

frequency buzzing noise audible to the listener (Thompson, 2002). Devices that deliver the speech signal through a DAI (i.e. Phonak Zoomlink) may produce unwanted noise if the connection between the hearing instrument and receiver/DAI is poor. The listener may also encounter unwanted noise when distance between the transmitter and receiver degrades the FM transmission or when the signal is interfered by electronic equipment. It was thought that more subjects would perceive noise when utilizing one or more of the HAT devices, but this was not the case. It is possible that no noise occurred or that potential interfering noise was not audible to the hearing instrument user. However, in this study, interfering noise did not seem to be a factor.

### **Controlling for Hearing Instrument Differences**

To ensure the subjects' personal hearing instruments did not cause confounding differences in performance during the listening conditions, it was necessary to "read" the hearing instruments to record walk-in program settings as well as to program a t-coil memory if one was not present. Of the 17 subjects, only eight or slightly less than half (47%) entered the study with a t-coil program. For those eight subjects with t-coil programs, one (12.5%) had a t-coil program configured in one hearing instrument, while the other hearing instrument was not pre-programmed with a t-coil memory. Even with t-coil programs, it was necessary to optimize t-coil settings to control for any variability across instruments, since two of the listening conditions utilized the t-coil feature. Optimizing t-coil settings was achieved by obtaining STS-SPLITS measures. These measures were of interest because they provided information as to whether the t-coil response was providing as much output as the hearing instrument's microphone.

Initially, of the 34 hearing instruments analyzed, the average STS-SPLITS measure prior to any adjustments to the telegain offset feature in the fitting software was -5.23 dB (SD=5.73). In other words, most t-coils within the hearing instruments were not optimized, according to the FONIX test measures, to match the instrument's microphone response, but -5.2 dB is not significantly less than the  $\pm 3$  dB range of optimal measures. The variability among the individual hearing instruments, however, causes concern that some hearing instrument users may experience less than optimal performance when utilizing a t-coil. Although manufacturers typically measure t-coil responses along with other measures of a hearing instrument, audiologists would be of service to their patients if they ensured the t-coil was in optimal position before enabling the patient to utilize the t-coil. Verifying the t-coil performance in addition to hearing instrument's performance is essential. In addition to coupler test measures used in this study, quantifying t-coil performance can be performed using a newly developed protocol for real ear measures, which more accurately reflects the performance of the t-coil at ear level (Yanz & Pehringer, 2003).

Furthermore, the amount of adjustment to the telegain offset required to achieve optimal t-coil responses varied greatly among the hearing instruments. On average, the telegain offset value needed to be adjusted by +5.1 dB (SD=5.6) to achieve STS-SPLITS within  $\pm 3$  dB, but the range of adjusted telegain offset values needed varied anywhere from 10.5 to -1.5. In addition, it currently is not clear as to what the relationship is between telegain offset adjustments and associated t-coil response. The shaded regions of Table 5 illustrate the amount of telegain offset adjustment and the associated STS-SPLITS change that resulted for each hearing instrument. One can see that, for example, Subject HI04's right and left hearing instruments both needed telegain adjustments of +10.5 dB to achieve STS-SPLITS values within defined limits ( $\pm 3$  dB),

but this amount of adjustment did not correspond with the same amount of dB change that resulted in the STS-SPLITS measure. For Subject HI04's right hearing instrument, a telegain offset adjustment of +10.5 resulted in a STS-SPLITS change of only +5.3 dB to obtain a final STS-SPLITS of -2.1, while the same amount of adjustment (+10.5) increased the STS-SPLITS value by a much larger amount (12.2 dB) to achieve a final STS-SPLITS value of 2.9 dB for this subject's left instrument. As a result, this unbalanced relationship made adjustment time consuming and somewhat frustrating.

In addition, six hearing instruments (6/34, 17.6%) from four subjects could not be adjusted to fall within the  $\pm 3$  dB STS-SPLITS criterion due to reaching the limits of the telegain off-set limits. In these instances, once the maximum adjustment of 10.5 dB was made in the software and further adjustments could not be made, the STS-SPLITS value at that maximum level of adjustment was accepted. For example, t-coil responses from both hearing instruments from two subjects (HI13 and HI14) could not be optimized. For the first subject (HI13), the STS-SPLITS for both hearing instruments fell within  $\pm 5.5$  dB of optimal levels, rather than the established  $\pm 3$  dB. In this specific case, the STS-SPLITS were -5.5 dB, indicating that the t-coil response of this specific subject's hearing instruments were each set at 5.5 dB less than that of the hearing instruments' microphone response. Similarly, the STS-SPLITS of the second subject (HI14) were also less than optimal. Actually, the t-coil response from both hearing instruments for this subject were approximately within  $\pm 7$  dB. In other words, the STS-SPLITS for subject HI14 were actually poorer than for Subject HI13. Theoretically, poorer STS-SPLITS should result in poorer performance with HAT since these products rely on the t-coil response of the hearing instruments rather than the microphone response when using the hearing instrument alone. Interesting, both subjects performed essentially as well across the four conditions.

TABLE 5: Amount of telegain offset adjustments and corresponding change in STS-SPLITS values for each hearing instrument.

SUBJECT	EAR	WALK-IN TELEGAIN OFFSET	ADJUSTED TELEGAIN OFFSET	TOTAL ADJUSTMENT	INITIAL STS- SPLITS	FINAL STS- SPLITS	STS-SPLITS DIFFERENCE
HI02	RIGHT	0	6	6	-7.3	-1.7	5.6
	LEFT	0	6	6	-7.8	2.4	10.2
HI03	RIGHT	0	0	0	-3.3	-3.3	0
	LEFT	0	0	0	-2.5	-2.5	0
HI04	RIGHT	0	10.5	10.5	-7.4	-2.1	5.3
	LEFT	0	10.5	10.5	-9.3	2.9	12.2
HI05	RIGHT	0	0	0	-1	-1	0
	LEFT	0	0	0	0.8	0.8	0
HI06	RIGHT	0	10.5	10.5	-7.5	-0.8	6.7
	LEFT	0	10.5	10.5	-10	1.1	11.1
HI07	RIGHT	10.5	10.5	0	1.8	1.8	0
	LEFT	10.5	10.5	0	-0.9	-0.9	0
HI08	RIGHT	0	9	9	-5.2	-0.1	5.1
	LEFT	0	10.5	10.5	-9.2	0.2	9.4
HI09	RIGHT	10.5	10.5	0	1.4	1.4	0
	LEFT	10.5	4.5	-6	4.1	2.7	-1.4
HI10	RIGHT	0	10.5	10.5	-11	1.3	12.3
	LEFT	0	0	0	0.1	0.1	0
HI11	RIGHT	0	10.5	10.5	-16.5	-0.4	16.1
	LEFT	0	10.5	10.5	-8.3	-1.1	7.2
HI12	RIGHT	0	7.5	7.5	-6.4	0.5	6.9
	LEFT	0	7.5	7.5	-5.1	-1.7	3.4
HI13	RIGHT	0	10.5	10.5	-8.2	-5.5	2.7
	LEFT	0	10.5	10.5	-10.6	-5.5	5.1
HI14	RIGHT	0	10.5	10.5	-16.5	-7.5	9
	LEFT	0	10.5	10.5	-14.5	-7.2	7.3
HI15	RIGHT	4.5	4.5	0	2.7	2.7	0
	LEFT	4.5	4.5	0	2.6	2.6	0
HI16	RIGHT	6	10.5	4.5	-10.5	-6.7	3.8
	LEFT	6	-1.5	-7.5	4.4	2.6	-1.8
HI17	RIGHT	0	10.5	10.5	-7.8	-2.2	5.6
	LEFT	0	10.5	10.5	-6.7	-5.6	1.1
HI18	RIGHT	0	0	0	0.3	0.3	0
	LEFT	0	0	0	-2.5	-2.5	0



For example, Subject HI14 obtained a hearing instruments only score of 78% whereas the average score across the three remaining HAT listening conditions was 84%. Why less than optimal t-coil responses resulted in essentially equivocal performances between hearing instruments only conditions and conditions incorporating HAT remains unknown.

One explanation for this type of variability could be attributed to a potential artifact associated to instrumentation. As previously mentioned, matching t-coil responses to the hearing instrument's microphone response is important for the purpose of enabling the user to achieve a better SNR with the t-coil. For that reason, STS-SPLITS measures should be as close to zero as possible. In the beginning of this study, obtaining accurate t-coil responses was confounded by some interference caused by the CRT monitor that is part of the FONIX 6500 system. As illustrated in Figure 18a, when the monitor was on, it caused an artifact in the STS-SPLITS reading (STS-SPLITS 13.6 dB) resulting in a t-coil frequency response that was affected. In contrast, as illustrated in Figure 18b, reliable and accurate STS-SPLITS readings (STS-SPLITS 1.0 dB) were obtained with the generation of a corresponding t-coil frequency response that mirrored the microphone response when the monitor was turned off. To ensure accurate t-coil responses, the monitor screen was turned off before the response was recorded. The configuration of the FONIX 6500 system was limiting in this manner but is addressed by the manual guide, and interference can be reduced with the more recently introduced FONIX 7000 system. This adaptation to the protocol, however, controlled for any potential interferences that would have otherwise resulted in potentially inaccurate STS-SPLITS measurements.

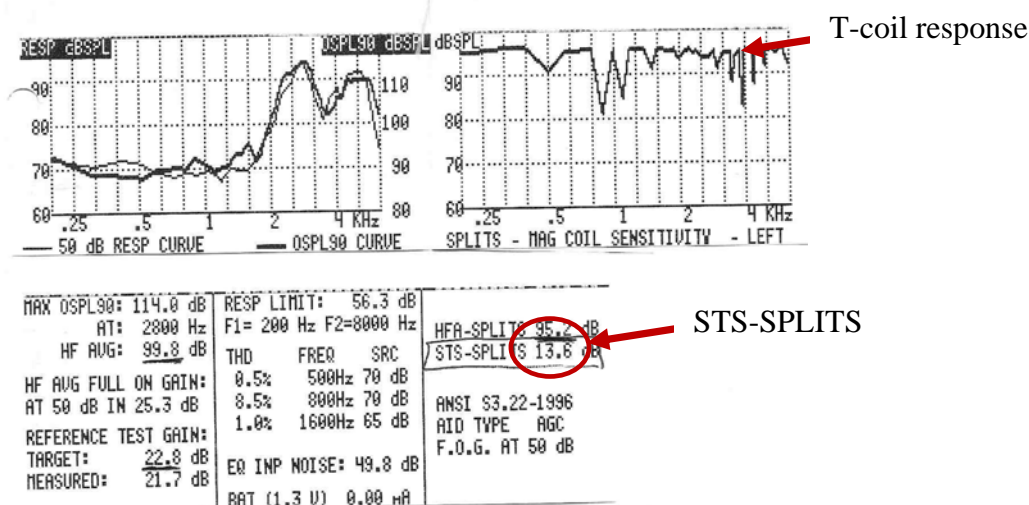


Figure 18a: Effects of monitor in the ON position on STS-SPLITS value and frequency response.

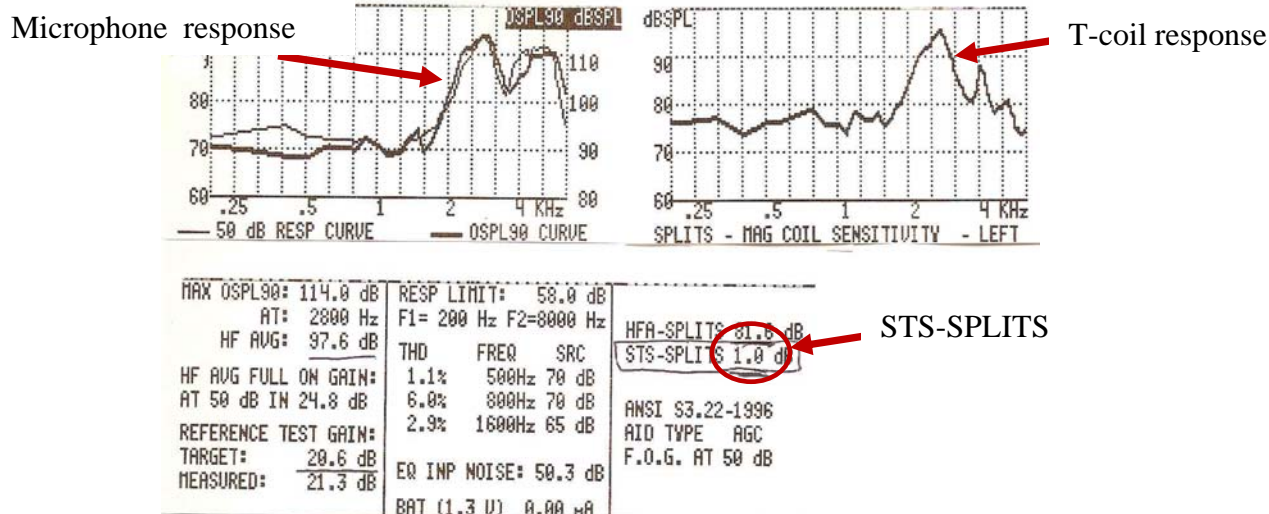


Figure 18b: Effects of monitor in the OFF position on STS-SPLITS value and frequency response.

## Limitations

The use of HAT in addition to hearing instruments did not produce results that were clinically significant. Perhaps the range of predetermined errors in each NU-6 word list may not have been sensitive enough to detect differences among the listening conditions. Collecting data on phonemic errors made by subjects with hearing loss may have produced results that could

have been more sensitive to specific frequencies that would explain why utilizing HAT was judged by most subjects with hearing loss to improve speech recognition and sound quality, even when performance was not clinically significantly different between listening conditions with and without HAT devices.

Another limitation to this study is that the characteristics of the sample group with hearing loss may not be representative of practicing audiologists and AuD students. Age, word recognition abilities, cognition, and severity and configuration of hearing loss affect individual differences that may be different from the population of individuals with hearing loss in Audiology.

It was also difficult to accurately address the issue of HAT convenience and ease of use while utilizing HAT devices. A better formatted questionnaire and enabling subjects to manipulate the devices themselves may have produced different results.

## **Conclusions**

From this study, it can be concluded that individuals with hearing loss who are users of hearing instrumentation generally performed better utilizing a HAT in addition to personal hearing instruments; however, the extent of the performance differences were not enough to achieve clinical significance. In other words, the HAT used in this study did not prove to be more effective in enabling individuals with hearing loss to differentiate between correct and incorrect responses when performing word recognition testing than using hearing instruments alone. Subjectively, HAT devices provide benefit in terms of improved speech recognition and sound quality.

Even though clinically significant differences were not detected between conditions utilizing a HAT device and the condition utilizing hearing instruments alone, the differences were statistically significant. Audiologists and AuD students who are currently users of hearing instruments may find it beneficial to incorporate the use of HAT during clinical practice. As the investigator of this study, curiosity as to how effective the use of HAT are in general, along with experience as an AuD student with hearing loss, led me to investigate this topic. Having a hearing loss makes it more difficult to perform speech recognition testing with ease. However, after finding a combination of strategies and HAT that are effective for me, performing the task is merely another procedure that enables me to become an effective clinical audiologist. This is a lasting goal that a study investigating the effectiveness of HAT can have for professionals, or any individual, with a hearing loss.

When used in conjunction with compensatory strategies, not only may accurately scored word recognition scores be achieved, but the use of these devices may minimize any negative effects of fatigue or stress that may play a role when assessing patient performance throughout the day. It is possible that integrating other compensatory strategies could generate clinically significant performance differences across various listening conditions. Not all individuals perform equally as well utilizing one particular HAT device. Individuals with hearing loss must, therefore, experiment with different devices to determine which, if any, are beneficial for using in their listening situations. Employers cannot definitely determine that HAT devices effectively ensure that audiologists and AuD students with hearing loss will obtain accurate word recognition scores. Individuals must be evaluated independently to determine their ability to achieve accuracy. In addition, audiologists and AuD students with hearing loss may offer

experience and perspectives to the clinic that may be beneficial to both the patient population and clinical workplace.

### **Future Investigations**

Future investigation of the following issues would improve our knowledge about HAT and increase the awareness of the available HATs and their benefits:

1. Evaluate other HAT that route the intended signal differently (i.e. personal infrared systems and room induction loop systems), that may provide benefit for audiologists and other individuals when assessing speech recognition.
2. Evaluate the effectiveness of HAT for the general population, including other subsets of the hearing impaired population such as cochlear implant users who may rely more heavily on HATs to communicate.
3. Evaluate the effectiveness of HAT in other challenging listening situations (i.e. restaurants, vehicles, theaters, etc.).

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## APPENDIX A:

### Telephone Script

(In a loud and clear, slow voice)

Hello, my name is Stephanie Schutzenhofer. I am an Audiology student at Washington University. With the help of Dr. Valente and other audiologists at the Adult Audiology Clinic at Washington University, I am conducting a research study looking at different hearing assistive technologies that may improve hearing aid users' ability to understand speech better. Your audiologist \_\_\_\_\_ knows about the study and has agreed that it would be ok to contact you about the study, because you currently wear Widex hearing aids in both ears.

I am looking at the possible differences in the performance between various types of listening devices that are typically used with hearing aid wearers to improve their understanding of speech. This research will apply to audiologists with hearing loss who may benefit from using these devices to improve their accuracy when giving a hearing test. You may also learn more about various listening technologies that may be helpful to you in certain situations. I would like to invite you to participate in my study.

Are you interested in learning more about this project?    Yes [ ☐ ]    No [ ☐ ]

If you participate you will be asked to repeat words while using various listening devices in addition to your hearing aids. This will help us to determine which devices improve your understanding of speech if any. Your participation would take approximately one hour and take place at the Adult Audiology Clinic at the Central Institute for the Deaf. May I send you a consent form which further explains the study?

Yes [ ☐ ]    No [ ☐ ]

If YES: I will call you a few days after I send the consent form to answer any questions you may have, and if you would like to participate in the study, I will set up an appointment for you to come into our office. I will ask you to sign the consent at that office visit.

Thank you so much for taking the time to talk with me today.



## APPENDIX B:

Informed Consent approved by the Washington University's Human Research Protection Office



Form #2 HIPAA 1/06  
Human Research  
Protection Office  
☐ Adult ☐ Minor

### INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Participant	_____	HRPO Approval Number	_____
Principal Investigator	<b>Valente, Michael, Ph.D.</b> <small>Last, First Credentials</small>	PI's Phone Number	<b>(314) 362-7489</b>
Title of Project:	<b>Utilizing Hearing Assistive Technologies (HATs) to Assess Speech Recognition: Comparison of Word Recognition Scores Obtained by Hearing Aid Users</b>		

You are invited to take part in a research study by Michael Valente, Ph.D., Director of Adult Audiology at Washington University School of Medicine.

Please ask for an explanation of any words you do not understand.

You may want to talk about the study with your family or friends before you decide to be in it.

#### 1. Why is this study being done?

The purpose of this project is to test the effectiveness of various hearing assistive technologies (HATs) that may improve the ability of an audiologist with hearing loss to accurately measure word recognition scores in an Audiology clinic.

The project will also assess the preferences of the HATs that you will use in the study by answering questions about the sound quality and convenience of each HAT.

You are being asked to participate because you either have a bilateral sensorineural hearing loss and wear behind-the-ear hearing aids in both ears or you have normal hearing sensitivity and can provide your assistance in repeating words that Audiologists utilize to test speech recognition ability. Some Audiologists have hearing loss and may benefit from using HATs to perform speech recognition testing in an Audiology clinic.

## 2. What am I being asked to do?

If you have hearing loss, your participation will consist of one visit to the Division of Adult Audiology Clinic at Central Institute of the Deaf. At this visit, you will be joined by a normal hearing “listener” who will be participating at the same time. You will be asked to listen to the listener repeat words and score them as being correct or incorrect. You will use a different listening device with your hearing aids while the listener repeats 50 words each time for a total of four conditions. The listener will listen and repeat the words heard in a sound-controlled room, while you score the listener’s words outside the room. You will also be asked to complete a short questionnaire about the devices you used for this study. This will take approximately one hour.

If you have normal hearing, you will participate as the “listener” for the study. Your participation will also consist of one visit to the Division of Adult Audiology Clinic at Central Institute of the Deaf. At this visit you will be asked to sit in a sound-controlled room and repeat words from the recorded female version of the Northwestern University Auditory Test No. 6 as the subject scores the words as correct or incorrect. You will be provided a word list for each of the four conditions with some of the words already incorrect. This will provide the target score in which the subject’s score will be compared.

### How long will I be in the study?

Your participation in the study will take an hour of your time in one day.

## 3. What are the Costs?

There are **NO COSTS to you** to participate in the study. Michael Valente and The Adult Audiology Clinic at Washington University Medical Center are financially responsible for all tests and procedures during this study.

## 4. What are the Risks?

Likely: If you have claustrophobia (a fear of confined spaces) you should not participate because all the testing will take place in a sound controlled booth.

Less likely: One potential risk of participating in the study is that confidential information about you may be accidentally disclosed. We will use our best efforts to keep the information about you secure, and we think the risk of accidental disclosure is small. Please see the confidentiality section of this consent form for more information. Another potential risk is you may experience fatigue from exerting your best effort to listen under various listening conditions. If you need a break, you may ask to take a short break.

Rare: The questionnaire you will be asked to complete involves your personal opinions and may, but most likely not, cause discomfort. If you have any questions about an item, you may discuss them with the investigator. *You may choose not to answer any questions that make you feel uncomfortable.*

### What happens if I am injured because I took part in this study?

Injuries are unlikely to occur by participating in this study. Washington University investigators will try to reduce, control, and treat any complications from this research. If you feel you are injured because of the study, please contact the Investigator and/or the Human Research Protection Office Chairperson from Item 8. Decisions about payment for

medical treatment for injuries relating to your participation in research will be made by Washington University.

**5. Are there Benefits to taking part in the study?**

Possible benefit for a subject from this research includes exposure to different hearing assistive technologies that may be helpful in difficult communicative situations. The subject will be able to try different systems that he/she would not be able to do in a typical Audiology clinic. The possible benefits for society include providing information on whether using hearing assistive technologies are beneficial in Audiology clinics for Audiologists or Audiology students who have hearing loss and have difficulty scoring speech recognition tests. This research may also show which technologies would be more appropriate for clinical use.

**6. What other Options are there?**

Taking part in this research study is voluntary. You may choose not to take part in this research study or you may withdraw your consent at any time. Your choice will not at any time affect the commitment of your health care providers to administer care. There will be no penalty or loss of benefits to which you are otherwise entitled. Other than not taking part in the research, you may meet with an audiologist at the Division of Adult Audiology Clinic at Central Institute of the Deaf to discuss other commercially available hearing assistive technologies that may be similar to that being used in this research. If you are a student, participation or non-participation will not affect your grade or class standing in any way.

**7. What about Confidentiality?**

When it is important to your medical care, information about your participation in this research study will be put in your medical record.

Protected Health Information (PHI) is health information that identifies you. PHI is protected by federal law under HIPAA (the Health Insurance Portability and Accountability Act). To take part in this research, you must give the research team permission to use and disclose (share) your PHI for the study explained in the consent form.

**In addition to health information that may be created by the study, the research team may access the following sources of your health information to conduct the study: hospital/physician medical records and questionnaires or interviews.**

**The research team may share your information with:**

- Government representatives, to complete federal or state responsibilities
- Hospital or University representatives, to complete Hospital or University responsibilities
- Your primary care physician if a medical condition that needs urgent attention is discovered
- Michael Strube, statistician for this study

Once your health information is shared with someone outside of the research team, it may no longer be protected by HIPAA.

The research team will only use and share your information as talked about in this form. When possible, the research team will make sure information cannot be linked to you (de-identified). Once information is de-identified, it may be used and shared for other purposes not discussed in this consent form. If you have questions or concerns about your privacy and the use of your PHI, please contact the University's Privacy Officer, at 1-866-747-4975.

You may access your research record at any time by contacting Michael Valente at 314-362-7489.

**Your participation in this study is voluntary. If you decide not to sign this form, it will not affect**

- your treatment or the care given by your health provider.
- your insurance payment or enrollment in any health plans.
- any benefits to which you are entitled.

However, it will not be possible for you to take part in the study.

**If you sign this form:**

You authorize the use of your PHI for this research

- Your signature and this form will not expire as long as you wish to participate.
- You may later change your mind and not let the research team use or share your information (you may revoke your authorization).
  - To revoke your authorization, complete the withdrawal letter, found in the HIPAA section of the Human Research Protection Office website at <http://hrpo.wustl.edu>, or you may request that the Investigator send you a copy of the letter.
  - **If you revoke your authorization:**
    - The research team may only use and share information already collected for the study.
    - Your information may still be used and shared if necessary for safety reasons.
    - You will not be allowed to continue to participate in the study.

Please specify any contact restrictions you want to request for this study only.

(Example – no calls at home, no messages left for you, no –emails, etc.)

**8. Who do I call if I have Questions or Problems?**

If you have any questions, concerns or complaints about the study, or feel that you are injured because of the study call Dr. Michael Valente, Ph.D. at 314-362-7457. You can also contact Stephanie Schutzenhofer at 618-660-5777 If you wish to talk to someone else, or have questions or concerns about your rights as a research subject, call Dr. Philip Ludbrook, Chairman of the University's Human Research Protection Office, at (314) 633-7400 or (800) 438-0445.

9. The Principal Investigator (PI) may withdraw you from the study without your consent if considered appropriate. For safety, it may be in your best interest to allow follow-up outside the study. The PI will share any new information that could change how you feel about continuing in the study.

10. Being in a research study does not take the place of routine physical exams or visits to your own doctor and should not be relied on to diagnose or treat medical problems.

**I have read this consent form and have been given the chance to ask questions. I will also be given a signed copy of this consent form for my records. I give my permission to participate in the research described above, *titled: Utilizing Hearing Assistive Technologies (HATs) to Assess Speech Recognition: Comparison of Word Recognition Scores Obtained by Hearing Aid Users.***

\_\_\_\_\_  
Participant's Signature or Legally Authorized Representative Date Signature of person providing Informed Consent Date

*The HSC does not require participants to re-sign the consent (If designee, see guideline Who May Obtain Consent) form unless a change is made; the investigator, however, may ☐ choose to have participants sign annually.*

\_\_\_\_\_  
Relationship to Participant

*Thank you for your important contribution to research studies that are trying to improve medical care.*

The Notice of Privacy Practices is a separate document. It describes the procedures used by WUMC to protect your information. If you have not already received the Notice of Privacy Practices, the research team will make one available to you.

\_\_\_\_\_ I have been offered a copy of the Notice of Privacy Practices.  
Initial

**This form is valid only if the Human Research Protection Office's current stamp of approval is shown below.**

## APPENDIX C:

## Study Questionnaire

Please answer the questions below to the best of your ability. The purpose of this questionnaire is to get your perspective of the various hearing assistive technologies you used today, in terms of their sound quality and ease of use.

1. Before today, have you used a listening device in addition to your hearing aids?

☐ yes ☐ no If yes, please explain\_\_\_\_\_

2. Did the use of one or more of the listening devices help you understand better than using your hearing aids alone?

☐ yes ☐ no If no, please disregard questions 3-8

3. Of the 4 listening systems you used, which one enabled you to best understand the listener's words?

☐ Hearing aids and speaker ☐ FM system with DAI boot  
☐ FM system with neckloop ☐ NoizFree earhooks

4. Did any of the devices provide better sound quality than the others?

☐ yes ☐ no If yes, which one?

☐ Hearing aids only ☐ FM system with DAI boot  
☐ FM system with neckloop ☐ NoizFree earhooks

5. Did you encounter any distracting or unwanted noise while using any of the devices?

☐ Hearing aids only ☐ FM system with DAI boot  
☐ FM system with neckloop ☐ NoizFree earhooks

6. If you could choose to utilize any one listening condition to understand speech better, which one would you choose?

☐ Hearing aids only ☐ FM system with DAI boot  
☐ FM system with neckloop ☐ NoizFree earhooks

7. Before scoring the listener's words using each device, you had to adjust the volume to a level that was most comfortable for you. Which system was the easiest to adjust?

☐ Hearing aids only ☐ FM system with DAI boot  
☐ FM system with neckloop ☐ NoizFree earhooks

8. Rank the order in amount of time in which it took to set up each listening system. (1 = least time, 4 = most time).

\_\_\_Hearing aids only

\_\_\_FM system with DAI boot

\_\_\_FM system with neckloop

\_\_\_NoizFree earhooks

9. If you could choose the most convenient listening condition, which one would you choose?

\_\_\_Hearing aids only

\_\_\_FM system with DAI boot

\_\_\_FM system with neckloop

\_\_\_NoizFree earhooks

10. Is there anything you would like to add that was not asked by the questions above?

## APPENDIX D:

## Questionnaire Results

General use of the HATs				
	<b><u>Yes</u></b>	<b><u>No</u></b>		
1) Have you used a listening device with your HAs?	2/17 (11.8%) *	15/17 (88.2%)		
2) Did the listening devices help better than HAs alone?	15/17 (88.2%)	2/17 (11.8%)		
Sound quality of the HATs (15 responded)				
	<b><u>FM/neckloop</u></b>	<b><u>FM/DAI boots</u></b>	<b><u>Earhooks</u></b>	<b><u>HA only</u></b>
3) Which enabled you to best understand speech?	5/15 (33.5%)	8/15 (53.4%)	2/15 (13.4%)	0
4) Which provided better sound quality? **	5/15 (33.4%)	8/15 (53.4%)	1/15 (7%)	0
5) Did you encounter noise while using any of the devices?	1/15 (7%)	1/15 (7%)	1/15 (7%)	1/15 (7%)
6) Which would you choose to use?	5/15 (33.4%)	8/15 (53.4%)	1/15 (7%)	1/15 (7%)
Convenience of using the HATs				
7) Which was easiest to adjust? ***	6 (40.0%)	6 (40.0%)	1 (7%)	0
8) Rank the time it took to prepare each device:				
Least time (1)	3/15 (20%)	1/15 (7%)	0	11/15 (73.4%)
(2)	5/14 (35.7%)	6/14 (42.9%)	3/14 (21.4%)	0
(3)	3/14 (21.4%)	5/14 (35.7%)	5/14 (35.7%)	1/14 (7.1%)
Most time (4)	3/14 (21.4%)	2/14 (14.3%)	6/14 (42.9%)	3/14 (21.4%)
9) Which would you choose as most convenient?	3/15 (20.0%)	6/15 (40.0%)	0	6/15 (40.0%)
10) Additional comments?: 4 subjects had comments about the HATs in study				

\*One participant stated that he uses an amplified telephone device and another had tried using an assistive device for the television.

\*\* One subject did not perceive sound quality using any listening device was better than using hearing aids alone.

\*\*\* Two subjects did not answer but commented that they all took the same time or didn't know.